A study of galactic dynamics under modified Newtonian dynamics (MOND)(Abstracts of Doctoral Dissertations,Annual Report (from April 1995 to March 1996))

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journal or publication title	The science reports of the Tohoku University. Ser. 8, Physics and astronomy
volume	17
number	1
page range	171-171
year	1996-07-25
URL	http://hdl.handle.net/10097/25927

A study of galactic dynamics under modified Newtonian dynamics (MOND)

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Abstract

There is strong evidence that the *dynamical mass* of a galaxy or a cluster of galaxies determined from its motion with Newton gravity deviates significantly from the *luminous mass* determined from its light. Usually the existence of dark matter (or hidden matter) is assumed to reconcile the discrepancy. Opposite to the conventional hypothesis, Milgrom (1983a,b,c) argued that the discrepancy is removed if the gravity is assumed to deviate from Newtonian gravity in the weak acceleration limit. The hypothesis is called "Modified Newtonian Dynamics" (MOND). In this paper we examine the consequences of MOND in various situations, comparing with those of the conventional dark matter hypothesis.

First we have tried to determine the shape of the function $\mu(x)$ which determines how the gravitational field deviates from the Newtonian gravity, by using well observed rotation curves of spiral galaxies. It is found that the rotation curves are consistent with any forms of $\mu(x)$ proposed in the literature within the observational uncertainties. The result indicates that MOND produces good force field at least on the rotating disks of spiral galaxies.

To examine force field, produced by MOND in the three dimensional space, we apply MOND to the polar ring galaxy NGC 4650A, in which the rotating disk is surrounded by rings nearly perpendicular to the disk. That is, NGC 4650A has two rotation curves and gives us information on the three-dimensional distribution of gravitational forces. It is found that the equatorial and polar rotation curves predicted by MOND for the luminous matter in the disk and polar ring are more or less consistent with the observational data. It is remarkable because there is no adjusting parameter in MOND in contrast to the conventional dark halo hypothesis. The result indicates that MOND produces force fields in the three dimensional space consistent with observations as far as it is applied to steady state conditions.

Next, we apply MOND to time-dependent phenomena. At the begining of the formation of a galactic disk, its consistuent was mostly in the form of gas. The disk evolves with forming stars as well as changing the distribution of mass due to the effect of viscosity. We apply MOND to such a disk evolution by assuming that the time scale of star formation is comparable to the viscous time scale. We have found that when most gas is converted to stars, an exponential like distribution of stars and a nearly flat rotation curve arise, which are in good agreement with observed properties of spiral galaxies. Similar result is obtained if we use Newtonian dynamics with dark halo.

Another time-dependent problem considered is the stability of self-gravitating galactic disks, in which two-dimensional N-body simulations are performed. The result of our numerical study indicates that the self-gravitating disk is more stable under MOND than the case under Newtonian dynamics.

All the results obtained in this paper indicate that MOND explains various observational phenomena without assuming the existence of dark matter. Although Newtonian dynamics can reproduce such phenomena by assuming the existence of dark matter, the MOND hypothesis seems to be superior because it has no adjustable parameter except for the one universal constant.